# AN EMPIRICAL INVESTIGATION OF THE U.S. ATLANTIC LONGLINE FLEET: SPECIFICATION AND ESTIMATION OF A MULTI-SPECIES COST FUNCTION WITH SUGGESTIONS FOR MISSING DATA PROBLEMS

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## I. Introduction

The 1999 Standing Committee on Research and Statistics (SCRS) of the International Commission for the Conservation of Atlantic Tunas estimated that the North Atlantic swordfish stock was at 65% of the biomass necessary to produce maximum sustainable yield (MSY). In addition, the SCRS considered the bigeye tuna stock to be overharvested as undersized specimens are still being caught. Recent SCRS stock assessments estimate that the Atlantic blue and white marlin stocks, as well as Atlantic sailfish/spearfish stock levels are critically less than necessary to produce MSY. Additionally, the National Marine Fisheries Service (NMFS) has identified these stocks as overfished (Office of Sustainable Fisheries, OSF, 2001).

Current management of Atlantic highly migratory species (HMS) fisheries uses a multipronged approach incorporating stock management, effort reduction, and capital reduction. Stock management activities include stock assessment, harvest quotas, and bycatch reduction measures. Fishing effort and fishing capital control actions comprise more restrictive permit allocation and permit buyout. Management goals under both the existing and pending legislation (see below) are to conserve the biological resource and to achieve economic efficiency within the fishery. In doing so, the transition costs and economic displacement to the fishery communities must be minimized according to the Magnuson-Stevens Fishery Conservation and Management Act (NMFS 1997).

On April 3, 2001 a bill (HR 1367) was introduced into the 107$^{th}$ Congress to provide for the conservation and rebuilding of overfished stocks of Atlantic HMS of fish. The objective of this legislation is to enhance the federal fishery management plan for Atlantic tuna, swordfish, and sharks finalized in 1999 through the establishment of time-area closures and vessel capacity reduction programs.

This paper describes an empirical model of the pelagic longline fleet (the predominate gear type used in these fisheries) that can be used to evaluate allocative and distributional economic effects to the industry of proposed changes in HMS regulations. Additionally, an EM algorithm is proposed to handle missing data problems that are typically present in empirical commercial fishery studies. Model results and implications are presented and discussed.

## II. Industry Background

The U.S. Atlantic pelagic longline fleet (PLL) fishes out of harbors from Maine to Florida and from Texas to the Caribbean and comprises at least 354 vessels ranging in size from 34 to 85 feet. The primary gear type is the midwater longline, which is "a continuous mainline suspended in the water by a series of floats with regularly spaced leaders attached that end with baited hooks" (NMFS 1997, p. 32). Presently, fishing occurs year around. In 1996, the fleet landed nearly 240,000 fish valued at $42 million dockside (Larkin, Adams, and Lee 2001). Landings in 1996 included swordfish, BAYS tunas (bigeye, albacore, yellowfin, and shipjack), dolphin fish (mahi-mahi), pelagic and large coastal sharks (i.e., makos, porbeagles, threshers, sandbars, silkys, blacktips, duskys, and hammerheads) and several other species (such as king mackerel, wahoo, oilfish, amberjack, and banded rudderfish). The diversity of landings reflects, in part, the undiscriminating nature of PLL gear and multi-fishery dependence of the fleet.

Overfishing, undersized bycatch, excess effort, and overcapitalization are the dominant problems plaguing Atlantic HMS fisheries and the PLL fleet. Both swordfish and bigeyed tuna stocks are considered "overfished". In 1998, discarded bycatch accounted for 58% of all finfish caught, 27% of the pelagic shark mortality, and 4% of swordfish mortality by the PLL fleet. Recent regulations reduced the pelagic shark quota for commercial vessels to 488 metric tons dressed weight (mt dw) per year. Proposed legislation HR 1367 allows the Secretary of Commerce to limit the cumulative number of PLL fishing sets in the Mid-Atlantic Bight for swordfish and tuna from June through September to 1,250. To further reduce swordfish and finfish bycatch, HR 1367 proposes cessation of use of PLL gear for HMS in the Gulf of Mexico Conservation Zone from Memorial Day to Labor Day. The legislation also proposes closure of the Northern Mid-Atlantic Conservation Zone from July 21 to August 31 and the Southern Mid-Atlantic Conservation Zone from September 1-30.

To lower latent effort, excess effort, and overcapitalization, HR 1367 will augment the limited entry system for swordfish, tunas, and sharks established by NMFS in 1999. The Pelagic Longline Capacity Reduction Program proposes to reduce the Atlantic PLL fleet through the surrender of directed swordfish, incidental swordfish, and Atlantic tuna permits and establishment of a reverse auction for such permits. Any PLL fishing vessel would be eligible for the program, with priority given to vessels that had significant landings of fish from the Mid-Atlantic Bight in the period 1992 through 1998. Currently, in order to participate in the swordfish or tuna fishery, persons must hold limited access permits (directed or incidental) for all three species, that is, swordfish, shark and tuna. As of December 1999, 1,894 permits were issued to 976 persons in 20 states. The majority of permits are registered in Florida (413), New Jersey (95), North Carolina (83), Louisiana (71), Maine (55), and New York (51).

To manage the accumulation of capital within the fleet, NMFS has placed restrictions on owners' ability to upgrade their vessels by placing upper limits on length, tonnage, and horsepower.

## III. Model Specification

Many previous studies in fisheries management have utilized duality theory to explain economic and technological characteristics associated with commercial fisheries. Dupont (1990) "integrates estimates of the harvest technology for vessels in a restricted access fishery with calculations of rent dissipation. Work by Squires (1987a, 1987b) and Kirkley and Strand (1988) uses duality theory to estimate harvest technologies for open access fisheries." Typically, analyses have relied on the assumption that firms earn some non-zero level of net income and inputs are sufficiently specified with a single measure (typically a function of vessel size and other inputs) that is fixed during a trip. These assumptions have allowed researchers to argue that firms participating in multiple fisheries attempt to maximize revenue subject to a single quasi-fixed input instead of maximizing profits directly. By assuming fixed input prices and aggregating all variable inputs into a single fixed input, maximization of the restricted profit function is equivalent to a revenue maximization problem. Thus, most of the literature has focused on production and output prices while little attention has been paid to inputs and factor prices.

For the most part, inputs cannot be varied during a fishing trip. Vessel operators must choose variable input levels prior to leaving the dock, that is, before the production process begins. It is our contention that fishing firms, especially those subject to trip quotas, make variable cost decisions at the trip-level. These variable cost decisions can be modeled as a cost-minimizing problem. This implies that captains choose a level of effort – based on an expected, stochastic catch distribution (Zellner, Kementa, and Dreze 1966) – to minimize variable costs. With input prices, output prices, and output quantities fixed at the trip level, profits are maximized when variable input costs are minimized. With duality theory we can derive an estimatable system of short-run input demand equations.

Using input cost and use data, we specify a dual flexible cost function in outputs, factor prices, and a fixed input, and use dummy variables to account for the location of the arrival port, vessel "expertise", trip length, and season. Since prevailing knowledge about the fishery and fleet does not dictate a particular functional form, we follow Dupont (1990) and adopt the quadratic form. The quadratic form offers an advantage over the Leontief or translog; the equations are estimated using data on variable quantities, rather than shares as required by the Leontief and translog functional forms. A normalized quadratic cost function for the Atlantic PLL fleet would be expressed as follows.

$$
\begin{aligned}
C\big(r,Y,Z,f(D)\big) = {} & \alpha_o + \sum_{i=1}^{3}\alpha_i r_i + \frac{1}{2}\sum_{i=1}^{3}\sum_{j=1}^{3}\alpha_{ij} r_i r_j \\
& + \sum_{k=1}^{5}\beta_k Y_k + \frac{1}{2}\sum_{k=1}^{5}\sum_{l=1}^{5}\beta_{kl} Y_k Y_l + \sum_{i=1}^{3}\sum_{k=1}^{5}\gamma_{kl} r_i Y_k \\
& + \mu Z + \omega Z^2 + \sum_{i=1}^{3}\lambda_i r_i Z + \sum_{k=1}^{5}\varsigma_k Y_k Z + \sum_{i=1}^{3}\rho_{in}^{m} r_i D_n^m \Big|_{mn}
\end{aligned}
\tag{1}
$$

In equation (1), $r_i$ represents the prices of light sticks, bait and fuel (i.e., variable inputs) normalized by the price of ice. Ice was chosen as the normalizing price due to lack of information about individual vessel's onboard ice making equipment. $C$ is trip-level total cost, also normalized by the price of ice. Normalized total cost is a function of normalized input prices ($r$), output levels ($Y$), a fixed capital input represented by vessel length ($Z$), and the dummy variables ($f(D)$): arrival port, vessel "expertise", trip length, and season. Using Shephard's lemma, the cost-minimizing demand functions can be easily obtained (i.e., $\partial C(\cdot)/\partial r_i = x_i(\cdot)$).

## IV. Empirical Model and Estimation

An empirical model was specified with normalized input prices ($r$) for light sticks, bait and fuel. The output quantities ($Y$) included BAYS tunas, dolphin fish, shark, swordfish, and other fish. Output prices (which are unavailable at the individual trip level) and output quantities were assumed fixed at the trip level. Four categories of dummy variables were included to account for observed heterogeneity within the PLL fleet and Atlantic HMS fisheries (Larkin, Adams, and Lee 2001), namely: geographic region of departure port ($D^G$), quarter ($D^Q$), trip length ($D^L$), and trip target ($D^T$). The geographic regions are the Caribbean, Gulf of Mexico, Northeast (base region), and the Mid-Atlantic/Southeast. The seasons (quarters) are January-March (base quarter), April-June, July-September, and October-December. Trip lengths based on number of sets are grouped as follows: 1-3 sets, 4-6 sets, 7-9 sets or 10-21 sets (base category). Trip length approximated by the number of sets per trip is also a measure of fishing effort expended at the trip level. Trip target categories are swordfish, BAYS tunas, shark, dolphin or other fish, or 'none' (base category). A trip was said to "target" a species if trip revenues for a species (or species group) exceeded 50% of total trip revenue. The input demand equations for light sticks ($i$=1), bait ($i$=2) and fuel ($i$=3) are given by:

$$x_i\big(r, Y, Z, f(D)\big) = \alpha_i + \sum_{i=1}^{3}\alpha_{ij} r_j + \sum_{k=1}^{5}\gamma_{ik} Y_k + \tau_i Z + \rho_{in}^{m} D_n^{m}\big|_{mn} \tag{2}$$

The input demand equations were estimated as a system of equations using 1996 logbook set and trip summary data collected by NMFS. All indices and variables are defined in Table 1.

**Table 1. Empirical Model Components**

| Symbol | Description |
|---|---|
| Indices: | |
| $i, j$ | Inputs (light sticks, bait, and fuel) |
| $k, l$ | Outputs (swordfish, BAYS tunas, dolphin fish, sharks, and 'other') |
| $m$ | Dummy Variable (geographic region, quarter, target, and trip length represented by G, Q, T, and L, respectively) |
| $n$ | Number of Levels for each Dummy Variable (1, 2, 3 or 1, 2, 3, 4) |
| Variables: | |
| $x_i$ | Cost-minimizing Input Demands (no. light sticks, lbs. bait, gal. fuel) |
| $r_i$ | Normalized Input Price ($/unit) |
| $Z$ | Fixed Capital Input (i.e., vessel length in ft.) |
| $Y_k$ | Output Quantity (no. landed/trip) |
| ${D^G}_n$ | Geographic Region Dummy Variables ($n$=3) |
| ${D^Q}_n$ | Quarterly Dummy Variables ($n$=3) |
| ${D^T}_n$ | Targeting Dummy Variables ($n$=4) |
| ${D^L}_n$ | Length of Trip Dummy Variables ($n$=3) |

The average trip used 1,317 light sticks, 1,831 pounds of bait, and 1,825 gallons of fuel (Table 2), however, the relatively large standard deviations indicate significant heterogeneity. Output per trip displayed even further heterogeneity as standard deviations were at least 50% above the means. Landings of swordfish, BAYS tunas, sharks, and dolphin averaged less than 30 fish per trip. The majority of trips departed from the Gulf of Mexico region (48%), which spans from Key West Florida to Texas. Trips in the sample data were dispersed throughout the year, although the last quarter (October-December) accounted for only 15% of trips. The majority of trips, as reflected by the percentage revenues, targeted swordfish (42%) and BAYS tunas (34%). In terms of trip length, as represented by the number of sets, the sample was evenly divided with the exception of the longest trips; only 16% of trips placed at least 10 sets. The variables used in this study are defined and described in Table 2.

The system of input demand functions given in equation (2) were appended with error term, $\varepsilon_i$ and estimated using generalized least squares (GLS). The errors are assumed independently and identically normally distributed with mean zero and constant variance (i.e., $\varepsilon_i$ is iid~N(0,$\sigma^2$)). Each error term is assumed correlated with the other error terms across equations in the system. This is a reasonable assumption because at the trip level input substitution is possible and likely if an operator decides to switch targeting strategies during a trip. Thus, the three input demand functions (equation 4) were estimated using Zellner's GLS procedure. Theoretical restrictions of symmetry and homogeneity were imposed.

## V. Results

All results pertain to the demands for the three inputs estimated, namely: light sticks, bait, and fuel. The estimated constant intercept parameters reflect, in part, the input demands associated with the "base" trip (i.e., the dummy variable from each category that was not included as an independent variable in the regressions and for the most part chosen arbitrarily). In particular, the base trip is one that concluded at a northeast port (i.e., from Maine to Virginia) between January and March and had fished 10 to 21 sets that resulted in over 50% of total revenues from dolphin or other fish in 1996. The estimated coefficients of the dummy variables represent mean differences in demands, *ceteris paribus*. Estimation results for the light stick, bait, and fuel equations are summarized in Tables 3-5, respectively, and discussed in separate sections below. Own-price elasticities of demand are shown in Tables 6-8 and also discussed below.

### V.A. Input Price Effects

The price of bait was statistically significant (at the 5% level) in determining the demand for light sticks and in determining the demand for bait. Increasing bait price increased the demand for light sticks suggesting that these two inputs are complements. Bait price and bait demand were inversely correlated indicating that bait is a normal good. Light sticks are also shown to be a normal good. Due to imposed symmetry, the price of light sticks was positively correlated with the demand for bait. The price of fuel was not statistically significant in explaining the demand for any input, even fuel, indicating that fuel price does not affect any input purchase decisions.

**Table 2. Summary Statistics for Model Variables**

| Symbol | Description | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| $Z$ | vessel length (ft.) | 56.39 | 14.32 | 32.00 | 86.00 |
| Inputs: | | | | | |
| $x_i$ | light stick use (no./trip) | 1,316.97 | 1,649.57 | 0.10 | 12,600.00 |
| $x_2$ | bait use (lbs./trip) | 1,830.81 | 1,660.85 | 100.00 | 10,000.00 |
| $x_3$ | fuel use (gal./trip) | 1,825.31 | 2,083.47 | 45.00 | 15,000.00 |
| $r_i$ | nor. light stick price ($/ea.) | 16.90 | 7.33 | 4.17 | 54.00 |
| $r_2$ | nor. bait price ($/lb.) | 22.98 | 11.04 | 2.00 | 100.00 |
| $r_3$ | nor. fuel price ($/gal.) | 25.13 | 9.72 | 7.58 | 86.00 |
| Outputs: | | | | | |
| $Y_1$ | swordfish (no./trip) | 22.84 | 45.17 | 0.00 | 453.00 |
| $Y_2$ | BAYS tunas (no./trip) | 29.02 | 43.42 | 0.00 | 352.00 |
| $Y_3$ | dolphin fish (no./trip) | 9.96 | 23.79 | 0.00 | 207.00 |
| $Y_4$ | sharks (no./trip) | 13.80 | 35.97 | 0.00 | 324.00 |
| $Y_5$ | 'other' fish (no./trip) | 3.80 | 9.26 | 0.00 | 91.00 |
| Geographic Region: | | | | | |
| $D^G{}_1$ | NC to Miami, FL | 0.30 | 0.46 | 0.00 | 1.00 |
| $D^G{}_2$ | TX to Key West, FL | 0.48 | 0.50 | 0.00 | 1.00 |
| $D^G{}_3$ | Caribbean | 0.08 | 0.28 | 0.00 | 1.00 |
| $D^G{}_4$ | ME to VA | 0.14 | na | 0.00 | 1.00 |
| Quarter (Season): | | | | | |
| $D^Q{}_4$ | January to March | 0.28 | na | 0.00 | 1.00 |
| $D^Q{}_1$ | April to June | 0.29 | 0.46 | 0.00 | 1.00 |
| $D^Q{}_2$ | July to September | 0.28 | 0.45 | 0.00 | 1.00 |
| $D^Q{}_3$ | October to December | 0.15 | 0.35 | 0.00 | 1.00 |
| Targeting Behavior: | | | | | |
| $D^T{}_1$ | % TR swordfish>50 | 0.42 | 0.49 | 0.00 | 1.00 |
| $D^T{}_2$ | % TR BAYS tunas>50 | 0.34 | 0.47 | 0.00 | 1.00 |
| $D^T{}_3$ | % TR shark>50 | 0.08 | 0.28 | 0.00 | 1.00 |
| $D^T{}_4$ | % TR none>50 | 0.10 | 0.30 | 0.00 | 1.00 |
| $D^T{}_5$ | % TR dolphin or other>50 | 0.06 | na | 0.00 | 1.00 |
| Length of Trip or Trip Effort: | | | | | |
| $D^L{}_1$ | 1-3 sets | 0.29 | 0.45 | 0.00 | 1.00 |
| $D^L{}_2$ | 4-6 sets | 0.30 | 0.46 | 0.00 | 1.00 |
| $D^L{}_3$ | 7-9 sets | 0.25 | 0.43 | 0.00 | 1.00 |
| $D^L{}_4$ | 10-21 sets | 0.16 | na | 0.00 | 1.00 |

V.B. Fixed Capital Input (Vessel Length) Effects

Vessel length was statistically significant (at the 1% level) for demand of each input. For every additional 10 feet in vessel length, vessel operators demanded 149.4 additional light sticks, 319.4 extra pounds of bait and 539.9 more gallons of fuel per trip. The statistical significance and sign of these coefficients indicate that variable input use per trip increases with vessel length.

V.C. Input-Output Relationships

The estimated coefficients on the output variables indicate the effect of increased marginal catch levels on the input demands. Swordfish and BAYS tunas were the only outputs whose landings had a statistically significant effect on the demands for all inputs. Increasing swordfish landings by 10 fish would require the following additional inputs: 135.8 light sticks (which are used to attract swordfish), 128.2 lbs bait, and 230.6 gallons of fuel. Increasing BAYS tunas landings by 10 would reduce the demand for light sticks by 40.3 while increasing the demand for bait 36.8 lbs and increasing the demand for fuel 58.3 gallons. The demand for bait was also significant in shark landings (10 extra sharks would increase demand for bait by 37.4 lbs). In addition, the demand for fuel increased 134.9 gallons if an additional 10 "other" fish were landed per trip.

V.C. Dummy Variable Effects

*V.C.1. Light Stick Demand (Table 3)*

- Trips that concluded (unloaded) in the Caribbean region demanded 1,129 more light sticks than those docking at a North Atlantic (i.e., Maine to Virginia) port.
- Trips where over 50% of total revenue was attributable to swordfish demanded 564 more light sticks than trips where dolphin or "other" fish comprised the majority of total revenues.
- Trips fishing 10-21 sets demanded from 818 to 1,752 more light sticks than trips placing fewer sets and that spent fewer days at sea.

*V.C.2. Bait Demand (Table 4)*

- Trips in the Caribbean region demanded the most bait, approximately 680 lbs more than trips in the North Atlantic region. Trips in the southeast Atlantic and the Gulf of Mexico demanded 524 and 430 pounds less, respectively, than trips in the North Atlantic.
- Winter trips (i.e., concluding January-March) demanded the most bait; trips docking in other seasons used from 360 to 457 lbs less bait.
- Trips where no single species accounted for more than 50% of total trip revenue demanded 764 lbs more bait than if dolphin or other fish accounted for the majority of total revenues.
- Trips placing more sets demanded more bait; trips placing from 1-3, 4-6, or 7-9 sets demand 1,057, 829, and 331 lbs, respectively, less bait than trips placing from 10-21 sets.

*V.C.3. Fuel Demand (Table 5)*

- Trips unloading in the Caribbean demanded, on average, 515 more gallons of fuel than trips concluding in the North Atlantic region.
- Trips placing from 10-21 sets demanded from 696 to 801 additional gallons of fuel than trips placing fewer sets.

**Table 3. Input Demand for Light Sticks (Estimated Parameter Values for Equation 2, *i*=1)**

| Variable | Symbol | Estimate[a] | *p*-value |
|---|---|---|---|
| Constant[b] | $\alpha_1$ | 909.17** | 0.0485 |
| Input Price Variables: | | | |
| Light Sticks ($r_1$) | $\alpha_{11}$ | -20.47** | 0.0266 |
| Bait ($r_2$) | $\alpha_{12}$ | 12.46** | 0.0120 |
| Fuel ($r_3$) | $\alpha_{13}$ | -2.45 | 0.6788 |
| Vessel Length ($Z$) | $\tau_1$ | 14.94*** | 0.0007 |
| Output Quantity Variables: | | | |
| Swordfish ($Y_1$) | $\gamma_{11}$ | 13.58*** | 0.0001 |
| BAYS Tunas ($Y_2$) | $\gamma_{12}$ | -4.03*** | 0.0061 |
| Dolphin Fish ($Y_3$) | $\gamma_{13}$ | -1.48 | 0.5500 |
| Sharks ($Y_4$) | $\gamma_{14}$ | 0.03 | 0.9870 |
| Other Fish ($Y_5$) | $\gamma_{15}$ | -0.06 | 0.9911 |
| Dummy Variables[b] | | | |
| Geographic Region: | | | |
| North Carolina to Miami, FL ($D^G{}_1$) | $\rho^G{}_{11}$ | 112.53 | 0.5084 |
| Texas to Key West, FL ($D^G{}_2$) | $\rho^G{}_{12}$ | 223.83 | 0.1743 |
| Caribbean ($D^G{}_3$) | $\rho^G{}_{13}$ | 1,129.39*** | 0.0001 |
| Quarter: | | | |
| April - June ($D^Q{}_1$) | $\rho^Q{}_{11}$ | -113.70 | 0.3880 |
| July - September ($D^Q{}_2$) | $\rho^Q{}_{12}$ | -204.49 | 0.1576 |
| October - December ($D^Q{}_3$) | $\rho^Q{}_{13}$ | 157.57 | 0.3002 |
| Targeting Behavior: | | | |
| % TR Swordfish >50 ($D^T{}_1$) | $\rho^T{}_{11}$ | 564.56** | 0.0381 |
| % TR BAYS >50 ($D^T{}_2$) | $\rho^T{}_{12}$ | 280.34 | 0.3183 |
| % TR Sharks >50 ($D^T{}_3$) | $\rho^T{}_{13}$ | 348.54 | 0.2898 |
| % TR None >50 ($D^T{}_4$) | $\rho^T{}_{14}$ | 537.62* | 0.0639 |
| Length of Trip or Trip Effort: | | | |
| 1-3 Sets ($D^L{}_1$) | $\rho^L{}_{11}$ | -1,751.97*** | 0.0001 |
| 4-6 Sets ($D^L{}_2$) | $\rho^L{}_{12}$ | -1,248.15*** | 0.0001 |
| 7-9 Sets ($D^L{}_3$) | $\rho^L{}_{13}$ | -818.76*** | 0.0001 |

Note: $R^2$= 0.62 and $R^2$adj = 0.60

[a] Single, double, and triple asterisks indicate statistical significance at the 10, 5, and 1% levels.

[b] The constant will reflect values of the base categories of the dummy variables for geographic region (Maine to Virginia), quarter (January - March), target (dolphin or 'other' fish), and trip length (10-21 sets).

**Table 4. Input Demand for Bait (Estimated Parameter Values for Equation 2, *i*=2)**

| Variable | Symbol | Estimate[a] | *p*-value |
|---|---|---|---|
| Constant[b] | $\alpha_2$ | 546.76 | 0.2494 |
| Input Price Variables: | | | |
| Light Sticks ($r_1$) | $\alpha_{21}$ | 12.46** | 0.0120 |
| Bait ($r_2$) | $\alpha_{22}$ | -12.81** | 0.0140 |
| Fuel ($r_3$) | $\alpha_{23}$ | 0.74 | 0.8715 |
| Vessel Length ($Z$) | $\tau_2$ | 31.94*** | 0.0001 |
| Output Quantity Variables: | | | |
| Swordfish ($Y_1$) | $\gamma_{21}$ | 12.82*** | 0.0001 |
| BAYS Tunas ($Y_2$) | $\gamma_{22}$ | 3.68** | 0.0156 |
| Dolphin Fish ($Y_3$) | $\gamma_{23}$ | -0.07 | 0.9790 |
| Sharks ($Y_4$) | $\gamma_{24}$ | 3.74** | 0.0348 |
| Other Fish ($Y_5$) | $\gamma_{25}$ | 3.80 | 0.4971 |
| Dummy Variables[b] | | | |
| Geographic Region: | | | |
| North Carolina to Miami, FL ($D^G{}_1$) | $\rho^G{}_{21}$ | -523.72*** | 0.0031 |
| Texas to Key West, FL ($D^G{}_2$) | $\rho^G{}_{22}$ | -430.43** | 0.0117 |
| Caribbean ($D^G{}_3$) | $\rho^G{}_{23}$ | 679.57*** | 0.0046 |
| Quarter: | | | |
| April - June ($D^Q{}_1$) | $\rho^Q{}_{21}$ | -360.46*** | 0.0086 |
| July - September ($D^Q{}_2$) | $\rho^Q{}_{22}$ | -456.82*** | 0.0024 |
| October - December ($D^Q{}_3$) | $\rho^Q{}_{23}$ | -410.05*** | 0.0094 |
| Targeting Behavior: | | | |
| % TR Swordfish >50 ($D^T{}_1$) | $\rho^T{}_{21}$ | 148.94 | 0.5974 |
| % TR BAYS >50 ($D^T{}_2$) | $\rho^T{}_{22}$ | 454.32 | 0.1197 |
| % TR Sharks >50 ($D^T{}_3$) | $\rho^T{}_{23}$ | 279.88 | 0.4125 |
| % TR None >50 ($D^T{}_4$) | $\rho^T{}_{24}$ | 763.50*** | 0.0114 |
| Length of Trip or Trip Effort: | | | |
| 1-3 Sets ($D^L{}_1$) | $\rho^L{}_{21}$ | -1,057.43*** | 0.0001 |
| 4-6 Sets ($D^L{}_2$) | $\rho^L{}_{22}$ | -829.34*** | 0.0001 |
| 7-9 Sets ($D^L{}_3$) | $\rho^L{}_{23}$ | -331.27** | 0.0424 |

Note: $R^2$= 0.59 and $R^2$adj = 0.58

[a] Single, double, and triple asterisks indicate statistical significance at the 10, 5, and 1% levels, respectively.

[b] The constant will reflect values of the base categories of the dummy variables for geographic region (Maine to Virginia), quarter (January - March), target (dolphin or 'other' fish), and trip length (10-21 sets).

**Table 5. Input Demand for Fuel (Estimated Parameter Values for Equation 2, *i*=3)**

| Variable | Symbol | Estimate[a] | *p*-value |
|---|---|---|---|
| Constant[b] | $\alpha_3$ | -564.93 | 0.3129 |
| Input Price Variables: | | | |
| Light Sticks ($r_1$) | $\alpha_{31}$ | -2.45 | 0.6788 |
| Bait ($r_2$) | $\alpha_{32}$ | 0.74 | 0.8715 |
| Fuel ($r_3$) | $\alpha_{33}$ | 0.23 | 0.9103 |
| Vessel Length ($Z$) | $\tau_3$ | 53.99*** | 0.0001 |
| Output Quantity Variables: | | | |
| Swordfish ($Y_1$) | $\gamma_{31}$ | 23.06*** | 0.0001 |
| BAYS Tunas ($Y_2$) | $\gamma_{32}$ | 5.83*** | 0.0011 |
| Dolphin Fish ($Y_3$) | $\gamma_{33}$ | 3.40 | 0.2563 |
| Sharks ($Y_4$) | $\gamma_{34}$ | 0.23 | 0.9103 |
| Other Fish ($Y_5$) | $\gamma_{35}$ | -13.49** | 0.0395 |
| Dummy Variables[b] | | | |
| Geographic Region: | | | |
| North Carolina to Miami, FL ($D^G{}_1$) | $\rho^G{}_{31}$ | -120.00 | 0.5605 |
| Texas to Key West, FL ($D^G{}_2$) | $\rho^G{}_{32}$ | -226.55 | 0.2541 |
| Caribbean ($D^G{}_3$) | $\rho^G{}_{33}$ | 515.41* | 0.0655 |
| Quarter: | | | |
| April - June ($D^Q{}_1$) | $\rho^Q{}_{31}$ | -194.60 | 0.2228 |
| July - September ($D^Q{}_2$) | $\rho^Q{}_{32}$ | -202.30 | 0.2486 |
| October - December ($D^Q{}_3$) | $\rho^Q{}_{33}$ | -169.00 | 0.3586 |
| Targeting Behavior: | | | |
| % TR Swordfish >50 ($D^T{}_1$) | $\rho^T{}_{31}$ | -481.67 | 0.1431 |
| % TR BAYS >50 ($D^T{}_2$) | $\rho^T{}_{32}$ | -91.73 | 0.7874 |
| % TR Sharks >50 ($D^T{}_3$) | $\rho^T{}_{33}$ | -473.47 | 0.2346 |
| % TR None >50 ($D^T{}_4$) | $\rho^T{}_{34}$ | 38.40 | 0.9128 |
| Length of Trip or Trip Effort: | | | |
| 1-3 Sets ($D^L{}_1$) | $\rho^L{}_{31}$ | -800.53*** | 0.0004 |
| 4-6 Sets ($D^L{}_2$) | $\rho^L{}_{32}$ | -698.77*** | 0.0004 |
| 7-9 Sets ($D^L{}_3$) | $\rho^L{}_{33}$ | -695.74*** | 0.0003 |

Note: $R^2$= 0.65 and $R^2$adj = 0.63

[a] Single, double, and triple asterisks indicate statistical significance at the 10, 5, and 1% levels, respectively.

[b] The constant will reflect values of the base categories of the dummy variables for geographic region (Maine to Virginia), quarter (January - March), target (dolphin or 'other' fish), and trip length (10-21 sets).

V.D. Own-Price Elasticities of the Inputs

Table 6 shows the own-price elasticities for different types of trips. Only light sticks and bait are included since the coefficient on fuel price was not statistically significant ($\alpha_{33}$; table 5). All computed own-price elasticity measures are negative suggesting that if price increases the optimal quantity demanded would fall. Also, all elasticities are less than one in absolute value indicating that the resulting change in demand will be less than the price change. In addition, the own-price elasticities of demand for lights sticks are larger than those for bait indicating the demand for light sticks is more responsive. More specific results follow the table.

**Table 6. Input Demand Elasticities for Light Sticks and Bait by Single Trip Characteristic**

| Variable | Light Sticks[a,b] | Bait[a,b] |
|---|---|---|
| Mean Own-Price Elasticity of Demand | -0.26 | -0.16 |
| Dummy Variables | | |
| Geographic Region: | | |
| Maine to Virginia (base) | -0.44 | -0.14 |
| North Carolina to Miami, FL ($D^G{}_1$=1) | ns | -0.28 |
| Texas to Key West, FL ($D^G{}_2$=1) | ns | -0.15 |
| Caribbean ($D^G{}_3$=1) | -0.06 | -0.07 |
| Quarter: | | |
| January through March (base) | ns | -0.14 |
| April through June ($D^Q{}_1$=1) | ns | -0.17 |
| July through September ($D^Q{}_2$=1) | ns | -0.18 |
| October through December ($D^Q{}_3$=1) | ns | -0.17 |
| Targeting Behavior: | | |
| % TR Dolphin or Other Fish >50 (base) | -0.88 | -0.22 |
| % TR Swordfish >50 ($D^T{}_1$=1) | -0.16 | ns |
| % TR BAYS >50 ($D^T{}_2$=1) | ns | ns |
| % TR Sharks >50 ($D^T{}_3$=1) | ns | ns |
| % TR None >50 ($D^T{}_4$=1) | -0.25 | -0.13 |
| Length of Trip or Trip Effort: | | |
| 1-3 Sets ($D^L{}_1$=1) | -0.95 | -0.36 |
| 4-6 Sets ($D^L{}_2$=1) | -0.33 | -0.19 |
| 7-9 Sets ($D^L{}_3$=1) | -0.24 | -0.14 |
| 10-21 Sets (base) | -0.12 | -0.10 |

[a] All other trip characteristics and variables were evaluated at their means.
[b] Note: "ns" indicates estimated parameter values that were statistically insignificant.

- The own-price elasticities of demand for light sticks and bait averaged 2.6 and 1.6, respectively, for a 10% change in price.

- Trips landing in the Caribbean region appear to have the most robust demand in that the demands for light sticks and bait were virtually unaffected by changes in own prices; a 10% price increase for light sticks and bait would reduce their respective demands by 0.6% and 0.7%, respectively. This result could reflect the lack of competition between ports in the Caribbean. For comparison, a 10% price increase for light sticks and bait would reduce their respective demands by 4.4 and 1.4%, respectively, in the Northeast (i.e., Maine to Virginia).
- The own-price elasticity of demand for light sticks was relatively insensitive to season (i.e., the mean elasticity did not change across seasons).
- The own-price elasticity of demand for bait was insensitive to seasonal changes.
- Trips targeting dolphin or other fish were associated with the largest own-price elasticities of demand for inputs; a 10% price of the input would reduce demand by 8.8% and 2.2% for light sticks and bait, respectively.
- Demand for both light sticks and bait became more elastic (although still inelastic) as the number of sets per trip declined; this effect was less pronounced in regards to bait. The own-price elasticities for light sticks ranged from 1% to 9.5% for a 10% price change. The own-price elasticity of demand for light sticks during trips that set from 1-3 sets was the largest in absolute value, nearly reaching one indicating a 1:1 relationship between price and demand.

V.E. Own-price Elasticities of Inputs by Joint Categories

Tables 7 and 8 summarize the own-price elasticities of demand for light sticks and bait for two dummy variable categories. Elasticities for fuel were not calculated since the coefficient on fuel price ($\alpha_{33}$; Table 5) was not significant. Since we have included four categories of qualitative variables in the model, the table includes elasticities for each combination of statistically significant dummy variables. While it is possible to calculate elasticities for all possible combinations of dummy variable values, given that there were 13 dummy variables, the calculation of many more elasticities would require more space than is allowed here.

Table 7 shows that the demand for light sticks on North Atlantic trips (base category) becomes increasingly elastic as the number of sets per trip falls; the own price elasticity of demand for light sticks ranges from 1.5% for trips placing more than 10 sets to 42.5% for trips placing less than four sets for a 10% increase in price. This response was also found for trips in the Caribbean region, but the elasticities were all less than 1.4%. This is likely due to the relatively heavy targeting of swordfish in the Caribbean region; since light sticks are crucial when targeting swordfish, trip level demand for light sticks in the Caribbean was highly inelastic as expected.

For trips where swordfish accounted for more than half of total trip revenues (i.e., a swordfish-targeted trip), demand for light sticks was inelastic no matter how many sets were placed. On the other hand, trips with no revenue-dominant species, trips with shark or other fish generating over 50% of revenues, and trips placing fewer sets had elastic demands for light sticks. Conversely, vessels placing the most sets were inelastic in their demand for light sticks. Also, for vessels in the Caribbean region, demand for light sticks was more inelastic during trips where revenue was generated primarily by swordfish.

**Table 7. Input Demand Elasticities for Light Sticks by Joint Trip Characteristics**

| | Geographic Region[a,b,c] | | Targeting Behavior[a,b] | | |
|---|---|---|---|---|---|
| Dummy Variable | Base | $D^G_3$=1 | Base | $D^T_1$=1 | $D^T_4$=1 |
| Targeting Behavior: | | | | | |
| Dolphin/Other (base) | n/a | n/a | | | |
| Swordfish ($D^T_1$=1) | -0.13 | -0.05 | | Symmetric | |
| None ($D^T_4$=1) | -0.20 | n/a | | | |
| Length of Trip: | | | | | |
| 1-3 Sets ($D^L_1$=1) | -4.25 | -0.14 | -1.50 | -0.61 | -1.76 |
| 4-6 Sets ($D^L_2$=1) | -1.50 | -0.07 | -2.59 | -0.21 | -0.30 |
| 7-9 Sets ($D^L_3$=1) | -0.87 | -0.06 | -0.40 | -0.14 | -0.23 |
| 10-21 Sets (base) | -0.15 | -0.05 | -1.00 | -0.08 | -0.10 |

[a] All other trip characteristics and variables were evaluated at their means.
[b] Elasticities were not calculated using parameter values that were statistically insignificant (n/a).
[c] Base category is Maine to Virginia. $D^G_3$=1 represents the Caribbean region.

Table 8 shows the own-price elasticities (in absolute value) associated with demand for bait. Again, the signs are consistent with economic theory and every calculation suggests an inelastic demand for bait. The demand elasticities ranged from -0.5 to -7.5% for a 10% price increase. In some cases, there seems to be the same pattern that was associated with light stick demand, namely: as the number of sets per trip increased, demand for bait became more inelastic. However, there are a few cases where this trend does not hold. Furthermore, the table suggests that trips concluding in the Caribbean display the most inelastic demand for bait and light sticks.

V.F. Results Summary

The demand for light sticks was found to vary by the cost of both light sticks and bait, the quantity of swordfish and BAYS tunas landed, the Caribbean region, swordfish targeting, vessel length, and the number of sets placed during the trip. All of these effects were expected since light sticks are used to attract swordfish, BAYS tunas are also commonly targeted, swordfish landings are highest in the Caribbean, and more fishing occurs when more sets are placed.

The demand for bait was affected by the price of light sticks and bait; vessel length; quantity of swordfish, BAYS tunas, and sharks landed; region; season; whether no specific species was targeted; and trip length (i.e., number of sets placed). Since more bait is typically used to attract larger fish, bait demand was most sensitive with the larger species. The large regional coefficients suggest significant location differences, most notable is the relatively large demand in the Caribbean and relatively small demand in the Northeast (where fewer swordfish and dolphin/other fish were caught). The lower demands for shorter trips would be expected since bait use and sets are directly related to some extent.

**Table 8. Input Demand Elasticities (absolute value) for Bait by Joint Trip Characteristics**

| | Season[a,b] | | | | Targeting[a,b] | | Trip Length[a,b,c] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Dummy Variable | Base | $D^Q_1$ | $D^Q_2$ | $D^Q_3$ | Base | $D^T_4$ | Base | $D^L_1$ | $D^L_2$ | $D^L_3$ |
| Geographic Region: | | | | | | | | | | |
| ME-VA (base) | 0.14 | 0.13 | 0.16 | 0.06 | n/a | 0.11 | 0.08 | 0.53 | 0.20 | 0.11 |
| NC-Mia ($D^G_1$=1) | 0.24 | 0.25 | 0.38 | 0.42 | 0.30 | 0.20 | 0.14 | 0.75 | 0.49 | 0.22 |
| TX-FL ($D^G_2$=1) | 0.15 | 0.15 | 0.17 | 0.16 | 0.15 | 0.12 | 0.16 | 0.20 | 0.16 | 0.10 |
| Caribb. ($D^G_3$=1) | 0.06 | 0.10 | 0.08 | 0.09 | n/a | n/a | 0.05 | 0.21 | 0.15 | 0.06 |
| Season: | | | | | | | | | | |
| Jan–Mar (base) | | | | | n/a | 0.12 | 0.08 | 0.28 | 0.16 | 0.13 |
| Apr–Jun ($D^Q_1$=1) | | Symmetric | | | 0.20 | 0.12 | 0.13 | 0.34 | 0.18 | 0.15 |
| Jly-Sep ($D^Q_2$=1) | | | | | 0.32 | 0.29 | 0.08 | 0.50 | 0.23 | 0.14 |
| Oct-Dec ($\boldsymbol{D^Q_3}$=1) | | | | | n/a | 0.16 | 0.12 | 0.42 | 0.17 | 0.13 |
| Targeting Behavior: | | | | | | | | | | |
| Dol./other (base) | | Symmetric | | | Symmetric | | 0.19 | 0.53 | 0.17 | 0.16 |
| None ($D^T_4$=1) | | | | | | | 0.09 | 0.22 | 0.13 | 0.12 |

[a] All other trip characteristics and variables were evaluated at their means.
[b] Elasticities were not calculated using parameter values that were statistically insignificant (n/a).
[c] Length of Trip: 1-3 Sets ($D^L_1$), 4-6 Sets ($D^L_2$), 7-9 Sets ($D^L_3$), 10-21 Sets (Base)

Fuel demand was found to vary by (1) vessel length, (2) landings of swordfish, BAYS tunas, and other fish, (3) the Caribbean region, and (4) number of sets placed. Fuel demand was highest in the Caribbean and for landing swordfish (swordfish landings were highest in the Caribbean). Fuel demand was nearly identical for trips placing from 4 to 6 sets or those placing from 7 to 9 sets, reflecting either an inefficiency in production or a need to reconsider these categories.

In general, the own price elasticities of demand for light sticks exceeded those for bait, but the elasticity of bait demand varied more due to the larger number of significant dummy variables. When calculated for each significant dummy variable, demand was inelastic in own price. In select seasons and regions, demand for light sticks was inelastic. The own-price elasticities of demand for light sticks ranged from 1.5 to 42.5% for a 10% price change. All demands associated with trips placing fewer than 7 sets were elastic in own price.

## VI. EM Algorithm for Missing Data Problems

The trip-level economic data (primarily cost information) on this fishery was collected under a voluntary program initiated in 1996. Complete data was received on nearly 20% of trips, covering all the heterogeneity within the PLL fleet, a roughly equal number of incomplete observations were discarded. Incomplete observations were those lacking responses to one or more trip-level economic questions (e.g., input prices and use, crew numbers and payment, and payments to the owner and/or captain). Missing economic information is a concern since it could introduce non-response bias. To address this issue we have proposed an algorithm for computing maximum likelihood estimates (MLE) from incomplete data. In future research we plan to apply this algorithm (i.e., the expectation mean (EM) algorithm) to data from this fishery in an attempt to extract additional information from the incomplete observations.

The MLE estimator of $\theta$, a vector of parameters, is the vector that maximizes the log-likelihood function of the observed data (i.e., $\theta'$). Initially, we want to generate an estimate of $\theta'$ by maximizing: $\ln L = \Sigma_i \ln f(y_i \mid \theta, x_i)$ where $y_i$ are the observed values, $f(\cdot)$ is the density function for $y_i$ and $x_i$ is data that enters the distribution. The EM algorithm proceeds as follows:

(1) E step: Form $H(\theta | \theta'_1, Y, X) = E[\Sigma_i \ln f(y_i^* | \theta, y_i, x_i)]$

(2) M step: Maximize $H(\cdot)$ to obtain $\theta'_{1+1}$

The E step involves forming a log-likelihood function for the latent data as if they were observed, then taking its expectation. This generates a "synthetic" $y_i^*$, equal to $H(\cdot)$, based on the initial estimate $\theta'_1$. When normality is assumed this is the same as forming a prediction of $y_i^*$ and then using $y_i^*$ to maximize the likelihood function. The M step uses the ordinary least squares (OLS) estimation procedure to obtain predictions of $\theta'_{1+1}$ on $X$. Thus, the OLS estimate of $\theta'_{1+1}$ equals $(X'X)^{-1}X'Y^*(\theta'_1)$. Once this estimate is obtained it is substituted back into the E step and the algorithm starts a new iteration. Under these conditions the algorithm converges to MLE and the generated "synthetic" $y_i^*$ are MLE estimates of the missing data. As the next step, we intend to use a Bayesian approach to generate these estimates then use the "new" larger data set to re-estimate the input demand equations and re-calculate the elasticities.

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